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Circulatory effects of dynamic exercise in children with a moderate to small ventricular septal defect

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INTRODUCTION, SUMMARY AND CONCLUSIONS

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Isolated ventricular septal defects occur in 20 to 25% of the children with a congenital heart disease^{26,35}. In most cases these defects are located high and anterior in the membranous septum³⁵. The size of the defect can vary widely, but its diameter is less than 1.0 cm in patients with a moderate to small left-to-right shunt and a normal pulmonary vascular resistance^{26,35}. The size of the defect and the pressure difference between left and right ventricle determine the amount of blood going through the defect. In a moderate to small defect and a normal pulmonary vascular resistance the main resistance to left-to-right shunting will be at the site of the defect.

The amount of blood flowing from left to right can be expressed as a percentage of the pulmonary blood flow; this ratio is called the shunt fraction.

Growth and mental development are normal in children older than 1 year with a left-to-right shunt fraction smaller than 67% and a normal pulmonary vascular resistance. Only few of them have symptoms attributable to the defect^{6,26,35}.

The natural history of the ventricular septal defect in children above the age of 2 years is of stable character. Follow-up studies have shown that in the majority of cases the shunt fraction stays the same, while in 17 to 20% of the cases the shunt fraction decreases^{7,8,50}. It is even possible that the defect closes spontaneously. According to Weidman *et al.*⁵⁰ this happens in 7% of the children above the age of 2 years with a smaller ventricular septal defect and in 1% of the larger defects. Keith²⁶ found that even in children above the age of 13 years, spontaneous closure still occurs in 4% of the cases. There is only a slight chance that the shunt will increase because with body growth the change in size of the ventricular septal defect is relatively minimal²⁶. When the ratio of the diameter of the defect and the body

surface area is related to age, the relative diameter of the defect decreases with advancing years.

The life expectancy in patients with a moderate to small defect, when not operated upon, was estimated by Bloomfield⁶ in 1964 to be 63 years. The major risk for these patients is bacterial endocarditis. Campbell⁷ and Keith²⁶ shared this opinion as to the prognosis in these patients. Campbell stated that patients with a left-to-right shunt fraction smaller than 50% have an almost normal life expectancy, since proper antibiotic treatment can nearly eliminate the risk of dying from bacterial endocarditis.

Therefore it seems justified not to operate upon children with a ventricular septal defect, a normal pulmonary arterial pressure, and a left-to-right shunt fraction of less than 50%, if they are asymptomatic and if their chestroentgenograms and electrocardiograms are normal³⁴.

When these children are not operated upon, one should not restrict them in their physical activity. These are the proceedings in our Department of Pediatric Cardiology, which is in agreement with the suggestions of the Report of the Intersociety Commission for Heart Disease Resources¹⁵. However, it is not quite clear what the effects of exercise are on the hemodynamics of patients with a ventricular septal defect.

Swan⁴⁵ investigated these effects in 1957 in thirty patients with a left-to-right shunt, of whom two had a ventricular septal defect and a normal pulmonary vascular resistance. In these two patients he found an increase in left-to-right shunt flow during exercise. Davies and Gazetopoulos¹³ studied the effects of exercise in 34 patients with a left-to-right shunt, of whom 5 had a ventricular septal defect and a normal pulmonary arterial pressure. The mean heart rate of these 5 patients during exercise was 104 min^{-1} , indicating a small workload. To determine the flows they used the Fick method and dye-dilution curves. A problem of using the Fick method is the impossibility to obtain a representative blood sample for the determination of the mixed venous saturation during exercise. In their study the mean of

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right atrial saturations was used. Applying the Fick method they found a decrease in shunt fraction during exercise in three out of four patients. Applying the dye-dilution method the shunt fraction decreased in three out of five patients, while the shunt fraction increased in the two remaining patients. Baedeker³ studied 28 patients with a left-to-right shunt; 4 had a ventricular septal defect and a normal pulmonary arterial pressure. The absolute workload was small, 30-60 watt. To determine the flows he also used the Fick method. In normal subjects, at various exercise loads, he determined the oxygen content of blood samples drawn from the superior vena cava, inferior vena cava, right atrium and pulmonary artery. Thus he estimated at the various exercise loads, which fraction of the mixed venous blood in the pulmonary artery came from the superior and which from the inferior vena cava. He used these results to estimate the oxygen content of the mixed venous blood during exercise in patients with a ventricular septal defect. He found in some cases an increase in left-to-right shunt flow during exercise, with no change in shunt fraction, whereas in other patients there was no change in left-to-right shunt flow and consequently a decrease in shunt fraction.

The above short survey of the literature shows that there is no uniformity in the results of measurements of a left-to-right shunt through a ventricular septal defect during exercise. This may partly be due to the use of the Fick method in calculating the different flows.

The absence of uniformity in the findings as well as the policy not to restrict patients who are not operated upon in their physical activity, led to the decision to study a representative group of patients with a ventricular septal defect, a moderate to small left-to-right shunt and a normal pulmonary vascular resistance.

The investigation included 35 children and adolescents. The ages varied between 9 and 18 years. The patients had no complaints and a normal body height and body mass for their age. In chapter 2 the clinical data are summarized and the methods used are described. Measurements during cardiac catheterization were made at rest and

at 25 and 50% of the maximum workload, or at rest and at 60% of the maximum workload. The maximum workload was assessed the day before cardiac catheterization using a progressive upright bicycle exercise test as described by Godfrey *et al.*¹⁹. During cardiac catheterization, catheters were introduced into the brachial artery and an antecubital vein. First a routine diagnostic right and left heart catheterization was carried out. Then the feet of the patient, who was in the supine position, were placed on the pedals of a bicycle ergometer. Then the following procedure took place: simultaneous recording of right and left ventricular pressures; measurement of blood flows by injection of indocyanine green into the pulmonary artery and sampling of blood from the ascending aorta; recording of pulmonary arterial wedge, pulmonary arterial, right atrial and aortic pressures. Then blood samples were taken from the aorta and right or left pulmonary artery to measure oxygen saturation, hemoglobin concentration and lactic acid concentration. All measurements were done at rest and at the various steady state workloads.

The pulmonary and systemic vascular resistances, the effective stroke volume of the left ventricle (left ventricle to aorta), the total stroke volume of the left ventricle (effective stroke volume plus shunt volume per beat), and the oxygen consumption were calculated.

In chapter 3 the results are presented. The patients were divided into three groups, with regard to the workload and the shunt fraction at rest. Group I consisted of 15 patients with left-to-right shunt fractions $\geq 20\%$, exercising at 25 and 50% of the maximum workload. Group II consisted of 10 patients with left-to-right shunt fractions $> 20\%$, exercising at 60% of the maximum workload. Group III consisted of 10 patients with left-to-right shunt fractions $< 20\%$, of whom 3 were exercising at 25 and 50%, and 7 at 60% of the maximum workload, subgroups IIIA and IIIB, respectively.

In chapter 4 the methods and the results are discussed. The maximum workloads of our patients are in agreement with the values obtained in normal children by Godfrey *et al.*¹⁹. Goldberg *et al.*²⁰ and Cumming¹² suggested that the exercise capacity of patients with a

ventricular septal defect and a moderate left-to-right shunt is lower than that of normal children. The difference between our findings and those of Goldberg *et al.* and Cumming might be explained by the use of different exercise tests.

We emphasize that in hemodynamic exercise studies in patients with a left-to-right shunt the dye-dilution method is more suited for measuring the blood flows than the Fick method, because of the impossibility to obtain a representative sample for the determination of the mixed venous oxygen saturation.

During exercise a considerable decrease in systemic vascular resistance was found and no change in pulmonary vascular resistance. When the systemic blood flow and effective stroke volume as found in our patients during exercise, were compared with data from normal children^{11,29}, the values in our patients were lower. To verify whether the size of the shunt fraction influences the effective stroke volume and the systemic blood flow, the 10 patients with the largest shunt fractions at rest were compared with the 10 patients with the smallest shunt fractions at rest. It appeared that those with the smallest shunt fractions at rest had a significantly higher effective stroke volume, a larger systemic blood flow and a smaller total stroke volume at rest. At exercise the differences between the two groups were smaller and not significant any more, because in the group with the largest shunt fractions the effective stroke volume increased.

The principal factors responsible for the flow through a ventricular septal defect are discussed. The left-to-right shunt flow did not change significantly during exercise at the different workloads, which is in agreement with the only slight increase in pressure difference across the defect and the increased resistance due to the non-laminar character of the shunt flow. The increase in systemic flow during exercise without a change in the left-to-right shunt flow, explains the decrease of the shunt fraction. Consequently the size of the defect may be underestimated when the systemic blood flow is temporarily increased through whatever cause. Therefore it is advisable to consider the shunt fraction in relation to the systemic blood flow.

From the results of this study, the following conclusions are drawn.

1. The left ventricle in patients with a ventricular septal defect and a normal pulmonary vascular resistance, does not fully compensate for the blood flow through the septal defect; consequently the effective stroke volume and systemic blood flow are lower than in normal children.
2. The left-to-right shunt flow does not change significantly from rest to exercise at different workloads. This is explained by the merely slight increase in pressure difference across the defect and by the increased resistance due to the non-laminar character of the shunt flow.
3. Exercise decreases the hemodynamic differences that exist at rest between patients with the largest and the smallest shunt fractions through an increase in effective stroke volume in patients with the largest shunt fractions.
4. It is advisable to consider the shunt fraction in relation to the systemic blood flow, because a temporary increase in systemic blood flow, through whatever cause, may lead to a decrease in shunt fraction and a consequent underestimation of the size of the defect.